memorandum

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Date	January 20, 2011
To	Ashley Allen, Jason Berner, U.S. Environmental Protection Agency (EPA)
From	Emily Giovanni, Lauren Parker, and Elena Besedin, Abt Associates Inc.
Subject	Literature Review of the Impacts of Urban Stormwater Runoff in the Chesapeake Bay Watershed

The Chesapeake Bay is the largest estuary in the United States. Its watershed covers more than 64,000 square miles, encompassing portions of six states (Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia) as well as the District of Columbia (CBP, 2009a). It is known as being a highly productive ecosystem, with more than 3,600 species of plants, fish and animals, and produces more than 500 million pounds of seafood every year (CBP, 2009b).

However, water quality in the Bay has declined precipitously over the last 50 years, with severe declines in submerged aquatic vegetation (SAV), fish, and shellfish. Along with increases in toxic substances and pollutants, eutrophication due to over-enrichment of nutrients has been a serious problem in the Bay for decades (Dauer, et al., 2000; Boesch, et al., 2001; CBF, 2009; CBP, 2009a; Langland, et al., 2003; others).

Although the decline is attributable to a wide variety of point and non-point sources, the Bay has the largest land-to-water ratio of any estuary in the world, making it particularly vulnerable to land use activities in the surrounding watershed (U.S. GAO, 2005). Stormwater runoff associated with a growing share of urban areas in the watershed is a significant and increasing source of nutrient and sediment pollution. This memo will provide a literature review of the contribution of urban stormwater to degradation in Chesapeake Bay, including 1) some brief background information on its regulatory history, funding, and current status, 2) an overview of current and future urban land use throughout the watershed, 3) a characterization of the relative impact of urban stormwater compared with other sources of pollution, 4) a description of the impacts of urban stormwater, and 5) a detailed characterization of urban fertilizers and urban pesticides in the Bay. Section 6 provides references.

1 Background

This section provides a brief regulatory history of the Chesapeake Bay restoration effort as well as a summary of its current status.

1.1 Regulatory and Funding History

Concern about the health of Chesapeake Bay began as early as the 1930s, with degradation becoming increasingly apparent throughout the 1950s and 60s. In the 1970s and 1980s, the EPA established that nutrient loading was a primary contributor to the degradation, causing problems such as hypoxia, eutrophication and widespread algae blooms. The Chesapeake Bay's regulatory history began in 1983 with the first Chesapeake Bay Agreement, which established the Chesapeake Executive Council to oversee and coordinate plans to protect and restore the Bay. In 1987, Congress formed the Chesapeake Bay Program, which is a partnership effort among several states, EPA, the Chesapeake Bay Commission, and the District of Columbia. That same year, the Chesapeake Bay Agreement set priority goals and commitments, including the reduction of controllable pollutants by 40% before 2000.

Following the 1987 agreement, there have been more than 10 additional legislative actions and agreements targeted at restoring the Bay, including numerous agreements establishing reduction targets, nutrient budgets for particular tributaries, and several reevaluations as it became clear that goals were not going to be met. In 2000, the Chesapeake 2000 Agreement committed signatories (including Maryland, Virginia, Pennsylvania, Delaware, New York, West Virginia, the District of Columbia, and EPA) to meet goals protective of aquatic life and human health, including the removal of the Bay and its tributaries from impaired water status by 2010. However, several intermediate reports between 2000 and 2010 showed that the ambitious goals laid out by the 2000 Agreement would not be met on time (Chesapeake Bay Reevaluation Steering Committee, 2005 as cited in U.S. EPA, 2010). In 2009, President Obama signed an Executive Order directing federal agencies, including EPA and the Departments of Agriculture, Commerce, Defense, Homeland Security, Interior, and Transportation (altogether the Federal Leadership Committee for the Chesapeake Bay), with drafting a plan for protecting and restoring the Bay. This regulatory history culminated with the publication of EPA’s multi-state total maximum daily load (TMDL) for Chesapeake Bay at the end of 2010 (U.S. EPA, 2010a).

The U.S. Government Accountability Office (U.S. GAO) estimated in 2005 that the Chesapeake Bay restoration effort up to that point had received $3.7 billion in direct funding from 11 federal agencies, states, and the District of Columbia, in addition to $1.9 billion in indirect funding. Of the direct funding before 2005, $1.7 billion went to water quality protection and restoration activities (such as upgrades to wastewater treatment plants), $1.1 billion went to sound land use activities (such as land acquisition), and $491 million went to vital habitat protection and restoration activities (such as wetland restoration). An additional $233 million of the direct funding went for living resource protection and restoration activities (such as oyster studies) and $156 million went to stewardship and community engagement programs (U.S. GAO, 2005).

Hasset, et al. (2005) conducted an analysis of stream restoration projects in the Bay watershed, and found a higher density of projects in the Bay per mile than anywhere else in the nation, with 75 to 100 projects per 600 river miles. Only 40% of the projects surveyed reported costs, but the total expenditure for those were $194 million. Extrapolating to all projects in the watershed results in costs of $426 million for stream restoration projects in the watershed between 1990 and 2003, with an average cost of $4,000.

1.2 Current Status

Despite the considerable regulatory history and expenditures in the restoration effort, the Bay is still considered to be in a degraded condition (U.S. EPA, 2010a). Several agencies have provided relatively recent accounts of the Bay’s status. The U.S. GAO assessed progress in Chesapeake Bay restoration in 2005, and found that despite establishing over 100 metrics for evaluating quantifiable progress in Bay quality (such as oyster populations), the Bay Program lacked an integrative approach that would allow it to collectively determine what the individual measures mean for the overall health of the Bay and achievement of the goals laid out in the 2000 Agreement (U.S. GAO, 2005). However, in a 2008 follow-up, the GAO reported that the Bay Program had developed a more comprehensive assessment approach that would facilitate a better overall view of the Bay’s health and restoration efforts (U.S. GAO, 2008).

The Chesapeake Bay Foundation (CBF, 2008) provides an overview of some of the trends in the Bay's productivity and the associated economic impacts. In its 2008 report, the Foundation estimates that in 1990, there were 800 million blue crabs in the Bay, but that this number had decreased to 260 million by 2007. The same report indicates that between 1998 and 2006, over 4,500 crab-related jobs were lost in Maryland and Virginia, with cumulative losses in excess of $600 million in the two states. There are also human health concerns associated with the Bay's degraded condition. CBF (2009) provides an overview of various human health threats presented by pollution in the Bay, including life-threatening bacterial infections, harmful algae, mercury, pathogens, and nitrates.

The CBP rated the overall health of the Bay during 2008 at 38%, with 21% of goals met for water quality, 45% of goals met for habitat and the lower food web, and 48% of goals met for fish and shellfish populations. The same assessment rated the watershed at 61% of restoration goals met, and indicated that 58% of pollution reduction efforts necessary to meet overall goals had been implemented. During 2008, 291 million pounds of nitrogen, 13.8 million pounds of phosphorus, and 3.3 million tons of sediments reached the Bay (CBP, 2009a).

A 2010 follow up documented an overall improvement in Bay health during 2009 to 45%, and noted several improvements including increased blue crab population and underwater grass beds. However, the report also noted that the Bay continues to have poor water quality, degraded habitats, and low populations of fish and shellfish (CBP, 2010c). For example, 12% of the Bay and its tidal tributaries met Clean Water Act standards for dissolved oxygen, while 26% met guidelines for water clarity. During 2009, 240 million pounds of nitrogen, 11 million pounds of phosphorus, and 2 million tons of sediment were estimated to reach the Bay (CBP, 2010c).

In response to President Obama's 2009 Executive Order (13508), the Federal Leadership Committee for the Chesapeake Bay (composed of representatives from a variety of federal agencies including EPA) published a Fiscal Year 2011 Action Plan (Federal Leadership Committee for the Chesapeake Bay, 2010). In the plan, the Committee summarizes planned actions, stating that federal agencies expect to spend $490 million on Chesapeake restoration efforts in fiscal year 2011, in addition to state and local expenditures.

2 Urban Land Use in the Chesapeake Bay Watershed

Decline in the health of the Chesapeake Bay has been linked to population growth and increases in the share of urban land in the watershed (Boesch, et al., 2001; Jantz, et al., 2005; Kaushal, et al., 2008; Roberts, et al., 2009; CBP, 2009a; Schueler, 2009; Schueler, 2010). This section will address past and future trends of urbanization in Chesapeake Bay.

2.1 Current Extent of Urban Land Use in the Chesapeake Bay Watershed

According to Beach (2002), coastal counties in the United States represent 17% of total acreage, but about half the total population, making these areas particularly vulnerable to the impacts of urbanization. This is compounded by trends that suggest that human impacts to watersheds outpace population growth (due to increasing per-capita consumption rates). For example, developed land in the conterminous United States increased 34% between 1982 and 1997. Land developed at a rate 1.8 times faster than the rate of population growth between 1982 and 1992, and 2.5 times faster between 1992 and 1997 (Beach, 2002). Elvidge, et al. (2004) used national coverage data sources to estimate that impervious surfaces cover approximately 112,610 km^2 in the United States, which is larger than the area covered by herbaceous wetlands (98,460 km^2) and only slightly smaller than the total area of Ohio.

Urbanization has occurred even faster in the Chesapeake Bay watershed, with population growth between 1980 and 2000 faster than in any other coastal watershed (Crosset, et al., 2004). Further, conversion of forest and agricultural land to development growing at a rate 2 to 3 times faster than population growth during the nineties (Boesch, et al., 2001). Between 1990 and 2000, impervious surface increased by 41% (2,473 km^2 to 3,480 km^2), while population increased by 8% (Jantz, et al., 2005; CBP, 2009a; Schueler, 2009). During the same time, the areas covered by at least 10% impervious surface area increased from 5,111 km^2 to 8,363 km^2 (an increase of 62%). Currently, impervious surfaces cover 21% of all urban lands in the watershed (USGS, 2007), and approximately 100 acres of forests in the Bay watershed are converted each day, primarily to roads or other developments (CBP, 2010a).

Most new impervious surface is low-density development at the edges of urban areas (Jantz, et al., 2005), following a pattern of low-density decentralized residential and commercial development. Schueler (2009) estimates that 75% of development in the watershed over the last decade has been low-density, outside designated smart growth areas, and Roberts, et al. (2009) estimate that lot sizes throughout the watershed increased by 60% between 1970 and 2000.

The EPA has developed a watershed model designed to simulate the Chesapeake Bay watershed, river flows, and the associated transport and fate of nutrients and sediments (Community Watershed Model; U.S. EPA, 2010c). This model have been in use since the inception of the CBP, but has undergone numerous upgrades and refinements. Using the most recent version of the model (Phase 5.3), EPA estimates that the Bay watershed is 65% forest/wooded, 24% agriculture, and 11% developed. CBP (2010) provides land use similar land use estimates: 58% forest, 22% agriculture, and 9% urban.

Schueler (2009) found a similar distribution of urban areas, estimating that they currently comprise 12% to 15% of the land area in the watershed, with 1.5 million acres of impervious cover and 3.8 million acres of suburban and exurban turf cover. Turf grass (75% of which is associated with residential lawns) covers the largest single fraction of pervious surfaces in the watershed (Schueler, 2010), encompassing up to 9.5% of the watershed. This represents an increase in turf cover of 80% between 1990 and 2000 (Schueler, 2009).

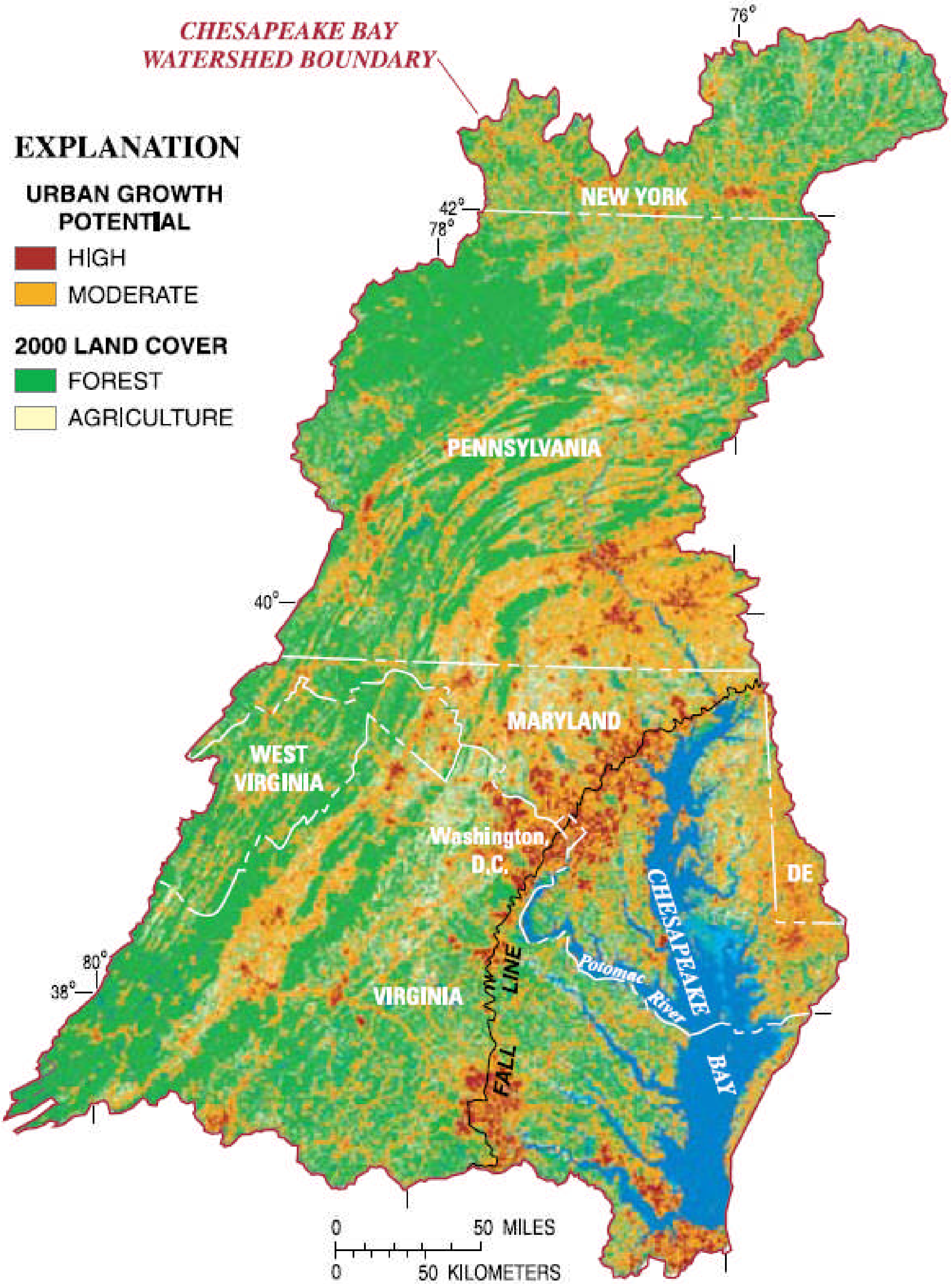
2.2 Projections of Future Extent of Urban Land Use in the Chesapeake Bay Watershed

Theobald, et al. (2009) used estimates of current and projected housing densities in the United States to estimate future trends in impervious cover and determine which watersheds are likely to be most vulnerable due to urbanization in the next 30 years. They found that approximately 83,700 km^2 of the conterminous United States is currently covered in impervious surface, and that this is expected to increase to 114,100 km^2 by 2030 (an increase of 36%; Theobald, et al., 2009).

Relative to nationwide trends, urban growth impacts may be more profound in the Chesapeake Bay watershed. Currently, about 17 million people live in the watershed, but population is expected to reach 18 million by 2020 (U.S. GAO, 2005), and be close to 20 million by 2030 (U.S. EPA OIG, 2007; Roberts, et al., 2009). The associated land development is also expected to be rapid. Schueler (2009) estimates that 1% of the watershed is developed each year, and Goetz, et al. (2004) predict an 80% increase in developed land area over the next 30 years. They expect that this development expansion will consume 5% of wetlands, 14% of forests, and 23% of agricultural land.

The U.S. Geological Survey (USGS, 2007) conducted an analysis to identify the areas of the Bay under especially high development pressure. Their results indicate that vulnerable areas include the Delmarva Peninsula, southern Pennsylvania, and the I-95 corridor. See *Figure 1* for a map of the most vulnerable areas identified by USGS.

Figure 1. Risk of Conversion of High Value Lands to Urban Areas by 2010 (Claggelt, 2007)



3 Relative Contribution of Urban Stormwater Runoff to Chesapeake Bay

Pollution in the Bay is attributable to a wide variety of point and nonpoint sources, and there have been several assessments aimed at identifying the relative contributions of each, as well as some documenting the changes over time. According to the CBP (2009a), the main sources of pollution in the Bay are agriculture, urban and suburban runoff, wastewater, and airborne contaminants.

According to CBP data (CBP, 2010b), urban stormwater is responsible for 15% of nitrogen, 16% of phosphorus, and 8% of sediment loads reaching the Bay, and rivals contribution of contaminants such as metals which are primarily attributed to industrial sources (CBP, 2010b). *Table 1* shows the relative contribution of urban stormwater to nitrogen, phosphorus, and sediment loadings compared with other sources. Other studies provide similar figures. For example, EPA's Office of the Inspector General reports that urban runoff accounts for 12% of nitrogen, 17% of phosphorus, and 10% of sediments in the Bay (U.S. EPA OIG, 2007).

Table 1. Relative Contributions of Sources of Surface Water Impairments in the Chesapeake Bay (CBP, 2010b)

Sources	Total Nitrogen	Total Phosphorus	Total Sediment
Agriculture	45%	44%	65%
Wastewater	21%	25%	<1%
Forest	20%	15%	18%
Urban Runoff	**8%**	**15%**	**16%**
Septic	4%	0%	0%
Non-Tidal Water Deposition	1%	<1%	0%

As Table 1 shows, urban runoff contributes a relatively smaller portion of pollutants compared with agriculture and point sources (wastewater). Due to this and the fact that developed lands are generally more expensive to address, early efforts have focused on relatively cost-effective control actions such as wastewater treatment plant upgrades and agricultural best management practices (BMPs; U.S. EPA OIG, 2007). Thus, although point sources and agricultural runoff have traditionally been more significant contributors of nutrients and other pollutants to the Bay, these sources have been better controlled than urban stormwater since restoration efforts began. This is supported by evidence that certain areas of the Bay dominated by point sources discharges have achieved demonstrable load reductions, while areas dominated by nonpoint sources have not decreased and in some cases have increased (Boesch, et al., 2001). Also, Boesch, et al. (2001) estimated that between the 1987 agreement and 2000, point sources of nitrogen and phosphorus were reduced by 15% and 58% respectively, while nonpoint sources were reduced by much smaller amounts -- 7% for nitrogen and 9% for phosphorus.

The result of these trends is that gains in reduction from some sources, including point sources and agricultural sources, are at least somewhat offset by rapid urban and suburban development in the watershed (Goetz, et al., 2004; U.S. EPA OIG, 2007). Urban and suburban runoff is the only source of pollution that is growing in the Bay (CBP, 2009a), and it is growing at a fast rate (Schueler, 2009). EPA's Office of Inspector General (OIG) estimates that nutrient loading from developed land increased by 12% to 16% between 1985 and 2005. Schueler (2009) estimates that in 1985, developed lands contributed 5% of nutrient loads but that this share had increased to 19% of nitrogen and 30% of phosphorus by 2005. The Chesapeake Bay Stormwater Training Partnership (CBSTP) did a similar calculation, estimating that urban runoff accounted for 2% of nitrogen and 5% of phosphorus to the Bay in 1985. By 2000, those numbers had more than tripled (CBSTP, 2010).

There are also several other studies that provide indications of the relative contribution of urban stormwater to Bay pollution. EPA's Assessment, TMDL Tracking and Implementation System (ATTAINS) database provides information about the conditions of the nation's surface waters, as reported by the states. The ATTAINS database does not provide summary data specifically for the Bay watershed. The highest spatial resolution of data is for Region 3 which consists of the following states: Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia. Although the Chesapeake Bay watershed includes only portions of these states (as well as a portion of New York), data for Region 3 can be used as an approximate reference. This is presented in *Table 2* (U.S. EPA, 2010b). These results suggest that urban stormwater is a cause of impairment in 11% of impaired river and stream miles and 2% of impaired lakes, reservoirs, ponds, bays, and estuaries in Region 3.

Table 2. Probable Source Contributions to Waters in EPA Region 3 (U.S. EPA, 2010b)

Probable Source Group	Assessed Waters with Listed Causes of Impairment		
	Rivers and Streams (Miles)	Lakes, Reservoirs, and Ponds (Acres)	Bays and Estuaries (Sq. Miles)
Agriculture	21%	1%	11%
Unknown	18%	86%	11%
Resource Extraction	13%	<1%	-
Natural/Wildlife	12%	6%	11%
Urban-Related Runoff/Stormwater	**11%**	**2%**	**2%**
Municipal Discharges/Sewage	6%	1%	11%
Unspecified Nonpoint Source	4%	<1%	1%
Hydromodification	3%	2%	10%
Habitat Alterations (Not Directly Related To Hydromodification)	3%	0%	11%
Atmospheric Deposition	2%	1%	11%
Other	2%	<1%	11%
Industrial	2%	-	11%
Aquaculture	<1%	-	-
Construction	<1%	-	-
Land Application/Waste Sites/Tanks	<1%	-	-
Legacy/Historical Pollutants	<1%	-	<1%
Recreation And Tourism (Non-Boating)	<1%	-	-
Silviculture (Forestry)	<1%	-	-
Spills/Dumping	<1%	-	0%
Commercial Harbor And Port Activities	-	-	<1%
Recreational Boating And Marinas	-	-	0%

Additionally, detailed information is available for the portion of Maryland that falls within the Chesapeake Bay watershed. The CBSTP used loading data from the CBP model to provide estimates of the relative impacts within Maryland. They found that while agriculture was the dominant source of nutrients to the Bay, urban and suburban runoff accounted for 12% of the nitrogen and 22% of the phosphorus loadings to the Maryland portion of the Bay in 2009 (*Table 3*).

Also, Groffman, et al. (2004) measured nitrogen fluxes in Baltimore County (the Gwynns Falls watershed, which drains to the Bay). They found that the nitrogen yield from urban and suburban subwatersheds was ten times higher than in forested subwatersheds. Forested areas had 95% nitrogen retention, while agricultural areas had 77% and suburban areas had 75%. The authors note that their estimate for suburban retention is higher than most of the literature, but that they did not include runoff associated with pet waste. Most of the nitrogen export observed by Groffman, et al. (2004) occurred during high-frequency, low-flow precipitation events rather than less frequent high-magnitude events.

Table 3. Relative Pollutant Contributions to Surface Waters in Maryland in 2009 (CBSTP, 2010)

Source	Total Nitrogen	Total Phosphorus
Agricultural	36%	44%
Wastewater	28%	22%
Urban/Suburban	**12%**	**22%**
Forest	14%	11%
Septics	8%	0%
Atmospheric Deposition	1%	1%

Finally, the USGS used the SPARROW model to estimate the rates of pollutant contributions to the Bay. *Table 4* shows the delivered yield of nutrients and sediments from different land use types per hectare. In the Bay watershed, urban land use has the lowest nitrogen and phosphorous loading rates relative to other sources (Brakebill and Preston, 2004). For sediment, urban land use contributes the greatest loadings to the Bay per unit area compared to agricultural and forest lands (Brakebill et al., 2010). The average yield from urban areas is almost 69 times greater than yields from agricultural lands; however, agricultural land use is the greatest source of total sediment load to the Bay due to higher overall acreage (Brakebill et al., 2010).

Table 4. Relative Contributions of Sources of Impairments to the Chesapeake Bay (in kg/ha/yr) (Brakebill and Preston, 2004; Brakebill, et al., 2010)

Sources	Total Nitrogen	Total Phosphorus	Total Sediment
Point Sources	25.49	0.76	-
Agricultural	3.16	0.10	570
Atmospheric	0.49	-	-
Urban	**0.45**	**0.04**	**39,280**
All Other Sources	-	0.06	-
Forest	-	-	~1

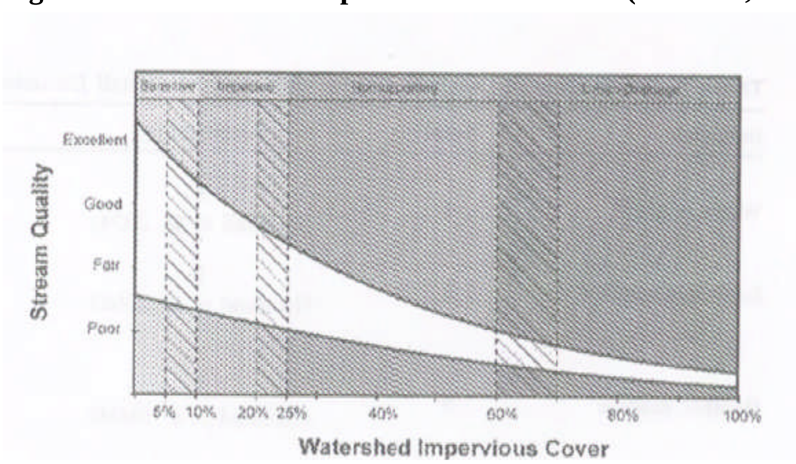
In its 2007 assessment of progress toward Chesapeake Bay restoration, EPA's OIG identified several challenges to reducing loads from developed and developing areas, including lack of community-level loading caps, shortage of up-to-date information on development patterns, limited funding, limited information and guidance on environmentally sensitive development, and others.

4 Impacts of Urban Stormwater in the Chesapeake Bay

Urban stormwater can degrade water quality and cause extreme hydrological alterations to aquatic ecosystems (Beach, 2002; Jantz, et al., 2005; National Research Council, 2008; USGS, 2009; Roberts, et al., 2009; Roberts and Prince, 2010; others). For example, urbanization and its associated increases in impervious cover profoundly alters the hydrologic regimes of subwatersheds, reducing the infiltration of rainwater into soils, such that stormwater flows to streams much more rapidly, in larger magnitudes, and with a large quantity of urban pollutants (Jantz, et al., 2005; NRC, 2008). Increases in the distribution of impervious surfaces fragment landscapes, and are correlated closely with increases in nonpoint runoff (Jantz, et al., 2005; USGS, 2009; Roberts and Prince, 2010) caused by sources such as leaf litter, vehicle emissions, pesticides, fertilizers, pet and urban wildlife waste, construction, infrastructure and many others (Roberts, et al., 2009). In receiving waterbodies, this contributes to sedimentation, turbidity, eutrophication, and hypoxia, which reduces submerged vegetation and causes other habitat impairments.[1] See *Appendix A* for a summary table (adapted from Beach, 2002) of studies documenting impacts of urbanization to aquatic ecosystems.

According to a model developed by Schueler (1994), hydrological, habitat, water quality, and biotic health indicators decline at around 10% of impervious surface cover (Beach, 2002; Schueler, et al., 2009). Schueler, et al. (2009) conducted a meta-analysis of peer-reviewed studies using the impervious surface cover model, and made adjustments to it to better reflect the relationship between impervious cover and stream quality. This model is shown in *Figure 2*. Similarly, Theobald, et al. (2009) characterize watersheds as "stressed" if they have more than 5% impervious surface, "impacted" with more than 10%, and "damaged" with more than 25%. In the Chesapeake Bay watershed, 21% of land in urban areas is impervious surface (USGS, 2007), and 75% of impervious cover is currently untreated or inadequately treated with stormwater practices (Schueler, 2009).

Figure 2. Reformulated Impervious Cover Model (Schueler, et al., 2009)



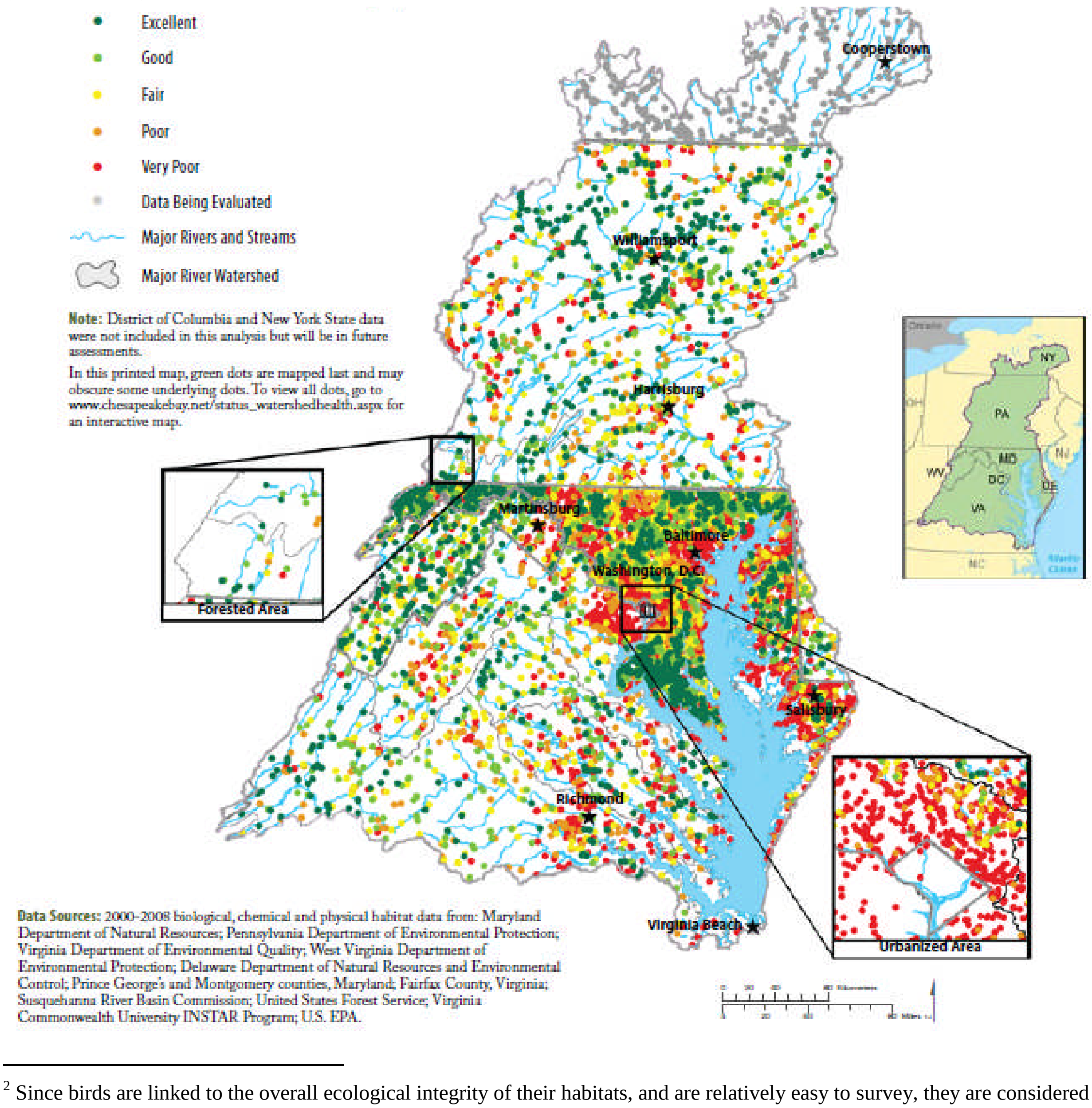
Due to the impacts associated with urbanization, aquatic communities associated with urban land uses have lower species diversity, less trophic complexity, altered food webs, altered community composition, and reduced habitat diversity (Dauer, et al., 2000). DeLuca, et al. (2004) used an index of marsh bird community integrity to evaluate marsh bird communities and wetland communities in the Chesapeake

[1] For a more comprehensive discussion of urban stormwater impacts, see National Research Council (NRC, 2008).

Bay.[2] DeLuca and colleagues found that marsh bird community integrity was significantly reduced when the amount of urban or suburban development within 500 meters and 1000 meters of the marsh exceeded 14% and 25%, respectively.

Between 2000 and 2008, CBP partners monitored the benthic macroinvertebrates of 10,452 streams throughout the watershed to determine stream health, finding that 5,459 streams were in poor or very poor condition, with the rest being fair, good, or excellent (CBP, 2010c). As shown in *Figure 3*, the streams categorized as poor or very poor tended to be associated with urban areas, while streams in agricultural or mined areas ranged from very poor to fair condition, and forested streams were mostly in good to excellent condition.

Figure 3. Benthic Macroinvertebrate Index of Biotic Integrity in the Chesapeake Bay Watershed (CBP, 2010c)



[2] Since birds are linked to the overall ecological integrity of their habitats, and are relatively easy to survey, they are considered good indicators of overall ecosystem health.

The frequency and distribution of sediment contamination and low oxygen events in the Bay are correlated with measures of urbanization, such as population density and land use (Dauer, et al., 2000). Urban stormwater runoff is responsible for impairments to over 1,500 miles of streams in the Chesapeake Bay watershed, and has caused flooding, streambank erosion, and habitat degradation in areas with as little as 2% impervious surface (CBP, 2001). As shown in *Table 5*, discharges from MS4s are the leading causes of impairment for freshwaters in EPA Region 3. For marine waters, non-point-source, wet-weather discharges are the primary source of impairment.

Table 5. Probable Source Contributions Related to Urban Runoff/Stormwater to Waters in EPA Region 3 (U.S. EPA, 2010c)

Probable Source Group	Percent of Impaired Waters		
	Rivers and Streams (Miles)	Lakes, Reservoirs, and Ponds (Acres)	Bays and Estuaries (Sq. Miles)
Municipal Separate Storm Sewer Systems (MS4s)	49%	45%	11%
Residential Districts (Including Small Res)	15%	38%	-
Wet Weather Discharges (Non-Point Source)	9%	16%	88%
Highway/Road/Bridge Runoff	14%	-	<1%
Wastes From Pets	12%	-	-
Impervious Surface/Parking Lot Runoff	<1%	-	-
Industrial/Commercial Site Stormwater Discharge (Permitted)	<1%	-	-
Unspecified Urban Stormwater	<1%	-	-

4.1 Pollutants Associated with Urban Stormwater

Urban stormwater causes profound hydrological changes (such as widening and deepening stream channels), including throughout the Bay watershed. Because impervious surfaces inhibit the ability of rainwater to seep into the ground, stormwater also increases the magnitude and speed of loadings of pollutants associated with urban areas, including urban fertilizers, urban pesticides, sediments, heavy metals, and others. For example, the quality of urban runoff contains anywhere from 20-30 times the concentration of nitrogen in natural waters and 4-100 times the concentration of phosphorus in natural waters (CBSTP, 2010). According to data derived from the Washington, D.C. subset of the EPA's Nationwide Urban Runoff Program, stormwater runoff from urban areas annually delivers approximately 2 pounds of phosphorus and 15.4 pounds of nitrogen per acre of impervious cover (MWCOG, 1983 as cited by CBSTP, 2010). The loading and impact of urban fertilizers and urban pesticides are discussed further in Section 5.

In addition to nutrients, excess sediment is one of the most profound contributors to degraded water quality in the Chesapeake Bay (Langland, et al., 2003). Urbanization can double background sediment yields, especially during the early stages of development. Erosion after construction can remain high due to increased stream corridor erosion caused by altered hydrology, with 2/3 of sedimentation from urban areas being attributed to channel erosion (Langland, et al., 2003). The remaining third is due to watershed sediment contribution. Sedimentation is a particular problem for Chesapeake Bay, due to its sediment-trapping nature (little or no sediment is exported to the ocean).

Urban stormwater is also a source of PCBs in the Bay watershed. Although banned since the 1970s, present sources of this pollutant are thought to be legacy pools of past point-source releases by manufacturers in industrial areas such as Baltimore (King, et al., 2004). This is consistent with data on hotspots surrounding these areas. However, some non-industrial sub-estuaries in the Bay watershed have also received PCB advisories, suggesting that nonpoint sources associated with use, storage, and disposal of the pollutant may be important as well. For example, King, et al., (2004) looked at measures of developed land use and PCB concentrations in white perch, and found a strong correlation. The highest concentrations of sediment PCBs were found near storm drain outlets, further highlighting the importance of stormwater.

4.2 Factors Influencing Impact of Urban Stormwater

Several factors can influence the impacts of urban stormwater. The most prevalent hydrological alteration to urban streams is channelization for flood control, which creates dramatic changes in stream responses to precipitation events (Foster, et al., 2000). For example, due to the channelization of the Anacostia River (a prominent sub-basin of the Chesapeake Bay), urban runoff plays a large role in the transport of hydrophobic organic contaminants such as PCBs to Chesapeake Bay.

Additionally, the impacts associated with urban stormwater can be compounded by other effects of urbanization, including stream burial, in which streams are directed into culverts, pipes, concrete-lined ditches, or paved over (Elmore and Kaushal, 2008). Headwater streams are particularly important for nutrient retention and habitat provision, but are very sensitive to changes in surrounding land use. Stream burial enhances the transport of pollutants from stormwater downstream. Elmore and Kaushal (2008) evaluated the degree and pattern of stream burial in the Baltimore area of the Chesapeake Bay watershed, and found that urbanized areas have disproportionately more buried streams than other areas, with 70% of headwater streams in Baltimore City being buried.

Climate variability can also play a large role in determining stormwater runoff, with high precipitation years causing more nitrogen to run off. For example, drought in 2002 followed by high flows in 2003 was correlated with severe water quality problems in the Bay, including hypoxia, changes in species composition, algae blooms, fish mortality, die-offs of oysters and aquatic vegetation, and human health risks (Kaushal, et al., 2008). Kaushal, et al. (2008) investigated how nitrate concentrations in Chesapeake Bay watershed streams interact with both urbanization and climate variability. They found that retention of nitrogen was highly variable according to land use type and weather. Forests retained 99% of nitrogen during dry weather, but this decreased to 76% in wet weather. For agriculture, the range was 94% down to 41%, and for surburban areas, retention was lowest, with 85% down to 35%. These results highlight the vulnerability of urban ecosystems due to high export during low flow compared with other land uses.

Roberts, et al. (2009) assessed the future contribution of various land uses to nutrient loading in the Bay using the SPARROW model. They expect that agricultural land is expected to decrease from 25% in 2000 to 22% in 2030, with an associated loading decrease of 10% for nitrogen and 7% for phosphorus. Additionally, while some increases in nitrogen loading were predicted for upstream areas, these were largely offset by downstream attenuation (biological uptake by stream organisms, and sedimentation onto stream and reservoir floors). However, as a direct result of urbanization, nitrogen was expected to increase by up to 33% in some basins.

5 Urban Fertilizer and Urban Pesticides Runoff in Chesapeake Bay

Urban stormwater contains urban fertilizers and urban pesticides, which Abt Associates has previously characterized under this work assignment. This section provides the pertinent information about urban fertilizers and urban pesticides in the Chesapeake Bay.

5.1 Urban Fertilizers

Fertilizers contain nitrogen and phosphorus, which are well documented contributors to the eutrophication, or over-enrichment, of surface waters of the U.S. including the Chesapeake Bay and its tributary streams (Fuhrer et al., 1999; Boesch et al., 2001; Law et al., 2004; Kemp et al., 2005; Fisher et al., 2006). A modeling study of two tributaries by Fisher et al. (2006) suggested that current N and P inputs are 4-20 times greater than during pre-development conditions. Specific studies of the fate and transport of nutrients have also been conducted (Lindsey et al., 2003; Ator et al., 2004).

While the impact of excessive nutrient loadings in the Bay is well studied and documented, most studies do not quantify the contribution of nutrients from various point and nonpoint sources, and when providing recommendations for nutrient reductions, they tend to focus on agricultural sources. For example, the fate and transport studies by Ator et al. (2004) and Lindsey et al. (2003) were conducted on the Delaware-Maryland-Virginia Peninsula which has a predominantly agricultural land use (48% agriculture, 7% urban). Boesch et al. (2001) focused exclusively on recommendations for reducing nutrient loads from agricultural land uses but lists “horticultural fertilization” as one of several impacts from sprawling suburban development which is discussed as an emerging issue. Boesch, et al. (2001) point out that nutrient loading reductions must primarily come agricultural sources (which are the largest contributors), but that to maintain reduced loading levels, loadings from new development will have to be limited.

Two studies estimate the percent nutrient contribution by various sources to the Bay. Megnien et al. (1995, as cited in Boesch, 2001) estimated that urban and suburban lands contributed 9% of nitrogen and 8% of phosphorus loadings to the Bay. More recently, based on the Chesapeake Bay Watershed Model (CBWM), runoff from developed land (urban and suburban) was estimated to contribute approximately 11% of the total nitrogen and 31% of the total phosphorus loading in 2008 (CBP, 2009a). In addition, despite significant efforts to reduce nutrient loadings throughout the watershed, developed lands and septic systems were the only source categories that increased from 1985 to 2008 while all others decreased (CBP, 2009a).Therefore, while no studies were located that directly quantified the contribution of urban fertilizer use and documented its impact on the Bay, data and documentation does exist that provide a link between urban fertilizer use and the Bay’s current impaired state.

In addition, there is indirect evidence that the impact of urban fertilizers on the Bay’s degraded water quality is widely accepted. For example, there are several initiatives targeted at reducing nutrient inputs from lawns such as the “Save the Crabcakes” campaign that included brochures, educational media programs, and slogans (Chesapeake Bay Social Marketing Initiative, 2005).There are also regulatory measures to limit fertilizer use on lawns such as the City of Annapolis’ 2009 ordinance limiting the use and sale of fertilizers. This ordinance was superseded by Maryland state regulations that same year and restricted the use and sale of fertilizer to low-phosphorus fertilizer (Maryland Annotated Code (MDAC), 2009). The MDAC also specified that fertilizer manufacturers are required to reduce the amount of available phosphoric acid resulting from application of their products to 50% of 2006 levels. Manufacturers that did not sell or distribute fertilizer prior to April 1, 2010 may not exceed an average of 1.5% available phosphoric acid in their products. In addition, all manufacturers are required to report the total pounds of phosphorus sold within Maryland (MDAC, 2009).

Two papers reporting results from surveys on urban fertilizer use also made statements attributing partial responsibility for the impairment of the Bay to urban fertilizers (Law, et al., 2004; Swann, 1999). In a survey of lawn fertilizer application rates, Law et al. (2004) stated that ongoing residential fertilizer practices, coupled with historic pollution, contribute to the non-point source pollution in the Bay. Similarly, in a survey to determine the effectiveness of nutrient educational programs, Swann (1999) acknowledged that improper lawn care practices including fertilizer application are partly responsible for nutrient inputs to the Chesapeake Bay.

5.1.1 Application rates and usage

Turf grass associated with urban development (e.g., residential laws and recreational areas where grass is cultivated and maintained) constitutes approximately 9.4% of the land area in the Bay watershed (Schueler, 2010). Increase in urban land and the associated turf grass is reflected in the steady increase of non-farm fertilizer use in Maryland from 13% of total fertilizer use in 1990, to 37% in 1999, and 45% in 2001 (Montgomery County, 2003). In the District of Columbia primary metropolitan statistical area, lawn fertilizers contribute approximately 4.7 million pounds of N and 560,000 lbs of P to the Bay each year (CBSMI, 2005).

The University of Maryland Cooperative Extension provides recommendations for lawn care which includes annual fertilizer application rates that vary depending on the type of vegetation and plant maturity (Gill, et al., 2001). For example, an application rate of 1 lb N/1,000 square feet per year (sq ft/yr) is recommended for lawns and 0 to 4 lb N/1,000 sq ft/yr for plants depending on their maturity (Gill et al., 2001; Ricigliano, 2004). Actual fertilizer application rates are affected by the level of turf maintenance desired by the owner, whether application is done by the owner or a landscaping company, and the type of lawn (e.g., golf course, residential lawn). Wible (2010, as cited in U.S. EPA, 2010c) estimates an annual rate of 1 to 2 lbs N/1,000 sq ft for low-input turf and 3 to 5 lbs N/1,000 sq ft for high-input turf. More specific application rates were estimated by Schueler and Holland (2000 as cited in U.S. EPA, 2010c) and are detailed in *Table 6* below.

Table 6. Fertilizer application rates (lbs/1000 sq ft/yr) in Maryland (Schueler and Holland, 2000 as cited in U.S. EPA (2010c)

Chemical	Golf Fairway	Greens	Home Lawn (do-it-yourself)	Home Lawn (lawn care services)
N	3.5	4.9	1.0-6.0	4.5-5.9
P	2.0	1.0	0.4	no data

Based on a survey conducted in two watersheds in Baltimore County, MD, Law, et al. (2004) found that nitrogen inputs varied spatially, based on socioeconomic factors and soil characteristics, and temporally, depending on the season. The authors found that there is a statistically significant relationship between higher application rates and more recently developed homes. They hypothesized that newer construction results in poor soil quality and consequently lawns require higher fertilizer application rates. The authors also estimated that lawn fertilizer application accounts for 53% of the total nitrogen input to the Glyndon watershed, with a mean fertilizer application rate of 1.99 lbs N/ 1,000 sq ft/yr. A summary of turf application rates from 12 other studies around the US was included in this study. With the exception of one outlier[3], estimates ranged from 0.49 to 11.06 lbs N/1,000 sq ft/yr.

[3] The outlier estimated a range of 0 to 40.65 lbs N/1,000 sq ft/yr.

Approximately 70% of the total turf area in the Bay watershed is residential lawns with half of these lawns maintained as high-input turf (Schueler 2010). Public turf (e.g. parks, median strips, golf courses, cemeteries) accounts for the remaining fraction with one-third maintained as high-input turf. Using these estimates, EPA (2010c) calculated that the total N *applied* to turf areas in the watershed is approximately 389 million lbs N/yr. Schueler (2010) estimated the nitrogen fertilization rate of turf areas at 215 million lbs N/yr.

The Maryland Department of Agriculture (MDA) published a registry of fertilizer manufacturers, their products, and the nitrogen, phosphorus, and potassium percentages for each product (MDA, 2010). However, this registry does not contain specific information about the application of these fertilizers as far as agricultural versus urban settings. We requested and are waiting for Maryland's Annual Fertilizer Tonnage Reports from the MDA which includes statistics on total agricultural and non-farm use trends between 1990 and 2004 (Montgomery County, 2003). The U.S. Geological Survey developed county-level estimates of non-farm fertilizer use expressed as nitrogen and phosphorus inputs for 1987 through 2001 (Ruddy, 2006). From this data, they developed a relationship between population density and non-farm fertilizer sales for 1992.

The CBWM includes estimates of the rate of nitrogen and phosphorus loadings from pervious urban land use to the Bay expressed in pounds per acre per year (lb/ac/yr). These values were based on total urban fertilizer sales with the CB watershed (Claggelt, 2010) but the year of this data is not known. The loadings are provided both as "edge-of-stream" and as "delivered" to the Bay, incorporating attenuation factors. This data was used in the model and values are available for monthly estimates of nitrogen and phosphorus fertilizer loads to urban pervious areas. These values are provided by land use type, including high and low intensity developed pervious surfaces, for the years 1985, 1987, 1992, 1997, 2002 and 2005 (U.S. EPA, 2010c). The CBWM also includes estimates of BMP implementation levels in 2008 and the acreage of urban lands that remain untreated by BMPs. Therefore, the CBWM may be the most comprehensive and consistent source of data for analyzing the effects of stormwater BMPs on reducing nutrient inputs from urban fertilizer use.

5.2 Urban Pesticides

Pesticides are synthetic organic chemicals used to control weeds, insects, fungi, and other pests in agricultural, commercial, industrial, transportation, public-health, and other applications (Denver and Ator, 2007). The impact of pesticides on human and ecosystem health have been documented in the U.S. generally, as well as in the Chesapeake Bay specifically (Ferrari, et al., 1997; Fuhrer et al., 1999; MPN, 2009). Exposure to individual pesticides has been studied and linked to numerous adverse health outcomes as summarized in *Table 7* based on a literature review by the Maryland Pesticides Network (2009).

Table 7. Possible Human and Ecosystem Health Effects Associated with Pesticide Use (MPN, 2009)	
Health Effects	**Study**
Human	
Glyphosate exposure can double the risk of developing non-Hodgkin lymphoma	Eriksson et al. 1998
Seven-fold increase of risk of childhood leukemia associated with household and garden pesticide use	Lowengart et al 1987
Increased rates of childhood leukemia, brain cancer and soft-tissue sarcoma linked to household pesticide use	Leiss et al. 1995; Gold et al. 1979; Lowengart et al. 1995; Reeves 1982; Davis et al. 1993; Buckley et al.1994
Carcinogenic implications of pesticides	Zahm, Hoar and Ward, 1998
Obesity and Type 2 diabetes	Lassiter et al. 2008
Increased risk of Parkinson's Disease, sometimes as much as 70%	Chou et al. 2009, Ascherio et al. 2006
Immune system	Porter et al. 1999
Endocrine system including birth defects including altered genitalia, language and mathematically skills, and other subtle biological responses; induce abortions and resorption of fetuses	Porter et al. 1999, Cavieres et al. 2002, Hayes et al. 2006
Proximity of mother to pesticide-treated fields during pregnancy increases risk of childhood autism by 6-fold	Roberts et al. 2007
Cardiovascular and reproductive system disorders; eye, liver, kidney or spleen; anemia; increased risk of cancer; blood-related problems	US EPA 2003a
Aquatic	
Renal and olfactory system damage, endocrine disruption, behavioral function disorders related to survival and reproduction	Moore and Waring 1998, Moore and Lower 2001
Alteration to microbial community structure, reduced populations	Perez, et al., 2007; Thom, et al., 2003
Increased sensitivity to select pesticides after long-term exposure	Pennington and Scott 2001

Endocrine disruptors received attention in 2006 with the discovery of male fish bearing immature oocytes in the Potomac River (MPN, 2009). In 2009, EPA announced an initiative to evaluate 67 pesticides as potential endocrine disruptors (MPN, 2009). Although the toxic effects of pesticides have been demonstrated at low levels (Odenkirchen and Eisler, 1988; Cebrian et al., 1992; Fernandez-Casalderry et al., 1992 as cited in Liu et al., 2001; MPN, 2009), there are several considerations that may amplify their toxicity. For example, there are limited research and data on the effects of chronic, long-term exposure, the additive and synergistic effects of exposure to multiple pesticides, and exposure to degradation by-products (Gilliom, 2006; Ferrari et al., 1997; Denver and Ator, 2007; MPN, 2009). In addition, because they are persistent compounds, they bioaccumulate through the food chain and adverse effects magnify at the top (MPN, 2009). Depending on the characteristics of the pesticide (e.g., mobility, degradation pathways) and the water (e.g., pH, salinity, metals concentration), pesticides can persist in groundwater systems for decades and surface waters for months (Liu, et al., 2001; Denver and Ator, 2007). The rate of degradation can be highly variable as demonstrated in a study on the hydrolosis of chlorpyrifos, an organophosphorus insecticide, in which rates of degradation varied from 24 to 126 days between the Patuxent and Susquehanna Rivers, respectively (Liu, et al., 2001).

5.2.1 Application Rates and Usage

Pesticides have been detected throughout the waters of the Chesapeake Bay and its tributaries (Gilliom, et al., 2006; Foster and Lippa, 1996; Lehotay, et al. 1998; Liu, et al., 2002 as cited in MPN, 2009), and in its wildlife (Zappia, 1996; Ator, 2008 as cited in MPN, 2009). Water quality data on pesticides are available for portions of the Chesapeake Bay watershed such as the Delmarva Peninsula and the Lower Susquehanna, Potomac and Delaware River watersheds, which were part of the National Water Quality Assessment (NAWQA) program (USGS, 2010). With respect to urban pesticides, researchers for the NAWQA program found that insecticides such as diazinon, carbaryl and chlorphyrifos and the herbicide prometon are more common in urban streams of the Susquehanna River Basin and the Delmarva Peninsula (Denver and Ator, 2007). In addition, following a phaseout of diazinon, concentrations of this insecticide decreased by 39% between 1998 and 2004 in an urban stream near Washington, D.C. (Phillips, et al., 2007).

Schueler (2001) estimated pesticide application rates on turf in the Bay watershed at six pounds per acre per year (lb/ac/yr)[4]. Schueler (2000 as cited in U.S. EPA, 2010b) estimated pesticide application rates on home lawns at 7.5 lb/ac/yr and on golf courses between 37.3 and 45.1 lb/ac/yr. MPN (2009) used national statistics of per-capita pesticide use to estimate an annual home and garden use of approximately 6.5 million pounds of pesticide in the Bay watershed.

There are significant initiatives in the Chesapeake Bay area to regulate the use, sale, storage and disposal of non-agricultural use of pesticides, especially in Maryland (Brown, et al., 2000). Under the Maryland Pesticide Applicators Law, licenses are required for any business providing pest control services, consultations or investigations, any public agency whose employees apply pesticides, or any farmer or nurseryman that intends to use pesticides for the purposes of agricultural production (Brown, et al., 2000).These entities are also required to maintain records with details such as the type of pest, acreage sprayed, and the name, concentration, and total amount of pesticide applied. The law also stipulates that public schools must develop and implement an Integrated Pest Management (IPM) system that is approved by the MDA. IPM programs must provide notification of each pesticide used on the school grounds, a 24-hour warning before pesticides are applied, and information on the location of the pesticide application (Brown, et al., 2000). As an additional resource, the MDA also maintains a searchable database that provides information on the pesticide name, active ingredient, licensed applicators, licensed dealers, manufacturers, pest name and application location; however, this covers all types of land use applications.

In Harrisburg, Pennsylvania, a pilot-project was conducted to reduce the purchase and use of pesticides using public education programs such as radio and television announcements, training sessions for retail employees, and informational postcards (McKenzie-Mohr & Associates 2007). As a result of this effort, a short-term decrease of 25-50% in pesticide sales was observed.

At the national-level, approximately 20% of pesticide use is not agricultural (MPN, 2009). These uses include household use (e.g., weed and insect killers, soaps, cleaners) and runoff from turf areas such as

[4] We are waiting for the full reference from T. Schueler for details on how this value was estimated.

lawns, gardens, golf courses, rights-of-way and landscaping (MPN, 2009; NOAA 2005 as cited in MPN, 2009). The spatial and temporal distribution of pesticides follows its pattern of use as it is detected in predominantly agricultural and urban land uses with low concentrations year-round and highest concentrations during active application in spring and fall (Ferrari, et al., 1997). Variations in concentrations can range by more than four orders of magnitude (Ferrari, et al., 1997). Urban lands tend to have highest concentrations of insecticides compared with agricultural lands, which have highest concentrations of herbicides (Ferrari, et al., 1997). The types of pesticides used overlap by 20% between the top 50 agricultural and the top 50 urban pesticides (Larson, et al., 1997 as cited in Ferrari, et al., 1997) but these trends may be changing. For example, metolachor was historically used primarily in agriculture; however, lawn, turf, rights-of-way, and landscaping application of metolachlor is now common (U.S. EPA, 1995 as cited in Debrewer, et al., 2005).

National statistics of total pesticide industry sales and usage, coupled with US Census data, have been utilized to approximate household use of pesticides and total amount of active ingredient used in various sectors of industry (Kiely, et al., 2004). These data are available and may be useful in scaling estimates of pesticide use to the CB watershed.

6 Sources

Ator, S.W., et al. 2004. Hydrologic and Geochemical Controls on Pesticide and Nutrient Transport to Two Streams on the Delmarva Peninsula. Scientific Investigations Report 2004-5051. United States Geological Survey.

Beach, D. 2002. Coastal Sprawl: The Effects of Urban Design on Aquatic Ecosystems in the United States. Pew Oceans Commission.

Boesch, D.F., R.B. Brinsfield, and R.E. Magnien. 2001. Chesapeake Bay Eutrophication: Scientific Understanding, Ecosystem Restoration, and Challenges for Agriculture. Journal of Environmental Quality 30: 303-320.

Brakebill, J., et al. (2010). Sources of suspended-sediment flux in streams of the Chesapeake Bay Watershed: a regional application of the SPARROW model. Journal of the American Water Resources Association 46(4).

Brakebill, J. and S. Preston. 2004. Digital Data Used to Relate Nutrient Inputs to Water Quality in the Chesapeake Bay Watershed, Version 3.0. Open-File Report 2004-1433. U.S. Geological Survey.

Brown, A., et al. 2000. Leaflet No. 35: Synopsis of the Maryland Pesticide Applicators Law and Regulations. UoMC Extension.

Cebrian, C., et al. 1992. Acute toxicity and oxygen consumption in the gills of Procambarus Clarkii in relation to Chlorpyrifos exposure. Bulletin of Environmental Contamination and Toxicology 49: 145-149.

Chesapeake Bay Foundation (CBF). 2009. Bad Water 2009: The Impact on Human Health in the Chesapeake Bay Region.

Chesapeake Bay Foundation (CBF). 2008. State of the Bay.

Chesapeake Bay Program (CBP). 2010a. Land Use. http://www.chesapeakebay.net/landuse.aspx?menuitem=14671

Chesapeake Bay Program (CBP). 2010b. Personal communication via email. Spreadsheet of summary results from CBPO Model Phase 5.3. received by Lauren Parker, Abt Associates Inc., from Rachel Streusand.

Chesapeake Bay Program (CBP). 2010c. Bay Barometer: A Health and Restoration Assessment of the Chesapeake Bay and Watershed in 2009.

Chesapeake Bay Program (CBP). 2009a. Bay Barometer: A Health and Restoration Assessment of the Chesapeake Bay and Watershed in 2008. CBP/TRS 293-09; EPA-903-R-09-001.

Chesapeake Bay Program (CBP). 2009b. Facts and Figures. http://www.chesapeakebay.net/factsandfigures.aspx?menuitem=14582

Chesapeake Bay Program (CBP). 2001. Backgrounder: Storm Water Management and the Chesapeake Bay.

Chesapeake Bay Social Marketing Initiative (CBSMI). 2005. Chesapeake Bay Social Marking Initiative 2004-2005 Final Report. http://www.epa.gov/nps/toolbox/surveys/Final_Chesapeake_Club_Report.pdf.

Chesapeake Bay Stormwater Training Partnership (CBSTP). (2010). From the Bay Watershed to Your Next Development Site: A Nutrient Primer for Stormwater Designers in the Chesapeake Bay Watershed.

Claggelt, P. 2007. Chapter 2: Human Population Growth and Land-Use Change. Circular 1316: Synthesis of U.S. Geological Survey Science for the Chesapeake Bay Ecosystem and Implications for Environmental Management. SW Phillips. United States Geological Survey.

Crosset, K.M., T.J. Culliton, P.C. Wiley, and T.R. Goodspeed. 2004. Population Trends Along the Coastal United States: 1980-2008. National Oceanic and Atmospheric Administration.

Debrewer, L.M., et al. 2005. Factors affecting spatial and temporal variability in nutrient and pesticide concentrations in the surficial aquifer on the Delmarva Peninsula. 2005–5257. U.S. Geological Survey, USDot Interior.

Dauer, D.M., S.B. Weisberg, and J.A. Ranashinghe. 2000. Relationships Between Benthic Community Condition, Water Quality, Sediment Quality, Nutrient Loads, and Land Use Patterns in Chesapeake Bay. Estuaries 23: 80-96.

DeLuca, W.V., C.E. Studds, L.L. Rockwood, and P.P. Marra. 2004. Influence of Land Use on the Integrity of Marsh Bird Communities of Chesapeake Bay, USA. Wetlands 24: 837-847.

Denver, J.M. and S.W. Ator. 2007. Chapter 8: The Occurrence of Pesticides in the Bay Watershed. Circular 1316: Synthesis of U.S. Geological Survey Science for the Chesapeake Bay Ecosystem and Implications for Environmental Management. SW Phillips. US Geological Survey, Reston, VA: 71.

Elmore, A.J. and S.S. Kaushal. 2008. Disappearing Headwaters: Patterns of Stream Burial Due to Urbanization. Frontiers in Ecology and the Environment 6: Research Communications.

Elvidge, C.D., C. Milesi, J.B. Dietz, B.T. Tuttle, P.C. Sutton, R. Nemani, and J.E. Vogelmann. 2004. U.S. Constructed Area Approaches the Size of Ohio. Eos 85: 233-240.

Federal Leadership Committee for the Chesapeake Bay. 2010. Fiscal Year 2011 Action Plan: Executive Order 13508, Strategy for Protecting and Restoring the Chesapeake Bay Watershed.

Ferrari, M.J., et al. 1997. Pesticides in Surface Water of the Mid-Atlantic Region. WRIR 97-4280. United States Geological Survey.

Fisher, TR, et al. 2006. Cultural eutrophication in the Choptank and Patuxent estuaries of Chesapeake Bay. Limnology and Oceanography 51(1, part 2): 435-447.

Foster, G and K. Lippa. 1996. Fluvial Loadings of Selected Organonitrogen and Organophosphorus Pesticides to Chesapeake Bay. Journal of Agricultural and Food Chemistry 44(8): 2447-2454.

Foster, G.D., E.C. Roberts Jr., B. Gruessner, and D.J. Velinsky. 2000. Hydrogeochemistry and Transport of Organic Contaminants in an Urban Watershed of the Chesapeake Bay (USA). Applied Geochemistry 15: 901-915.

Fuhrer, G.J., et al. 1999. The Quality of Our Nation's Waters: Nutrients and Pesticides. Circular 1225. United States Geological Survey. http://pubs.usgs.gov/circ/circ1225/pdf/index.html.

Gill, S., et al. 2001. Fertilizer Recommendations for Landscape Trees and Shrubs (For Professional Grounds and Landscape Contractors). Fact Sheet 789. University of Maryland Cooperative Extension,.

Gilliom, R.J. 2006. Pesticides in the Nation's Streams and Ground Water,1992–2001—A Summary. Fact Sheet 2006–3028. United States Geological Survey.

Goetz, S.J., C.A. Jantz, S.D. Prince, A.J. Smith, D. Varlyguin, and R.K. Wright. 2004. Integrated Analysis of Ecosystem Interactions with Land Use Change: The Chesapeake Bay Watershed. Ecosystems and Land Use Change, Geophysical Monograph Series 153: 263-275.

Groffman, P.M., N.L. Law, K.T. Belt, L.E. Band, and G.T. Fisher. 2004. Nitrogen Fluxes and Retention in Urban Watershed Ecosystems. Ecosystems 7: 393-403.

Hasset, B., M. Palmer, E. Bernhardt, S. Smith, J. Carr, and D. Hart. 2005. Restoring Watersheds Project by Project: Trends in Chesapeake Bay Tributary Restoration. Frontiers in Ecology and the Environment 3: 259-267.

Jantz, P., S. Goetz, and C. Jantz. 2005. Urbanization and the Loss of Resource Lands in the Chesapeake Bay Watershed. Environmental Management 36: 808-825.

Kaushal, S.S., P.M. Groffman, L.E. Band, C.A. Shields, R.P. Morgan, M.A. Palmer, K.T. Belt, C.M. Swan, S.E.G. Findlay, and G.T. Fisher. 2008. Interaction between Urbanization and Climate Variability Amplifies Watershed Nitrate Export in Maryland. Environmental Science and Technology 42: 5872-5878.

Kiely, T., et al. 2004. Pesticides Industry Sales and Usage: 2000 and 2001 Market Estimates. U.S. Environmental Protection Agency,Washington, D.C.

Kemp, W.M., et al. 2005. Eutrophication of Chesapeake Bay: Historical Trends and Ecological Interactions. Marine Ecology Progress Series 303: 1-29.

King, R.S., J.R. Beaman, D.F. Whigham, A.H. Hines, M.E. Baker, and D.E. Weller. 2004. Watershed Land Use Is Strongly Linked to PCBs in White Perch in Chesapeake Bay Subestuaries. Environmental Science and Technology 38: 6546-6552.

Langland, M., T. Cronin, and S. Phillips. 2003. A Summary Report of Sediment Processes in Chesapeake Bay and its Watershed. United States Geological Survey. Water-Resources Investigations Report 03-4123.

Law, N.L., et al. 2004. Nitrogen Input from Residential Lawn Care Practices in Suburban Watersheds in Baltimore County, MD. Journal of Environmental Planning and Management 47(5): 737-755.

Lehotay, S.J., et al. 1998. Agricultural pesticide residues in oysters and water from two Chesapeake Bay tributaries. Marine Pollution Bulletin 37: 32-44.

Lindsey, B.D., et al. 2003. Residence Times and Nitrate Transport in Ground Water Discharging to Streams in the Chesapeake Bay Watershed. 2003-4035. US Geological Survey.

Liu, B., et al. 2001. Hydrolysis of chlorpyrifos in natural waters of the Chesapeake Bay. Chemosphere 44: 1315-1323.

Maryland Annotated Code (MDAC). 2009. Title 6: Subtitle 2: 6-222. Low phosphorus fertilizer. from http://www.michie.com/maryland/lpext.dll?f=templates&fn=main-h.htm&2.0.

Maryland Department of Agriculture (MDA). 2010. "Listing of Fertilizers-Pesticides Registered". from http://www.mda.state.md.us/pdf/state_chemist/fert_pest.pdf.

Maryland Pesticide Network (MPN). 2009. Pesticides and the Maryland Chesapeake Bay Watershed: White Paper.Annapolis, MD.

McKenzie-Mohr & Associates. 2007. Reducing Residential Pesticide Use: White Paper. Southwest Florida Water Management District, from http://www.swfwmd.state.fl.us/files/database/social_research/Pesticides_Final_Report.pdf.

Montgomery County. 2003. The Use of Fertilizers in the State of Maryland.

National Research Council. 2008. Urban Stormwater Management in the United States: Executive Summary. Committee on Reducing Stormwater Discharge.

Odenkirchen, E and Eisler, R. 1988. Chlorpyrifos hazards to fish, wildlife, and invertebrates: a synoptic review Biological Report 85, 1.13. US Fish and Wildlife Service

Phillips, S.W., et al. 2007. Temporal Changes in Surface-Water Insecticide Concentrations after the Phaseout of Diazinon and Chlorpyrifos. Environmental Science and Technology 41(12): 4246-4251.

Ricigliano, D. 2004. Fertilizing Facts for Home Lawns. HG 103. University of Maryland Cooperative Extension.

Roberts, A.D. and S.D. Prince. 2010. Effects of Urban and Non-urban Land Cover on Nitrogen and Phosphorus to Chesapeake Bay. Ecological Indicators 10: 459-474.

Roberts, A.D., S.D. Prince, C.A. Jantz, and S.J. Goetz. 2009. Effects of Projected Future Urban Land Cover on Nitrogen and Phosphorus Runoff to Chesapeake Bay. Ecological Engineering 35: 1758-1772.

Ruddy, B.C., et al. 2006. County-Level Estimates of Nutrient Inputs to the Land Surface of the Conterminous United States, 1982–2001. 2006-5012. U.S. Geological Survey, UDot Interior,Reston, VA.

Schueler, T.R., L. Fraley-McNeal, and K. Cappiella. 2009. Is Impervious Cover Still Important? A Review of Recent Research. Journal of Hydrologic Engineering: 309-315.

Schueler, T. 2010. The Clipping Point: Turf Cover Estimates for the Chesapeake Bay Watershed and Management Implications. Chesapeake Stormwater Network Technical Bulletin No. 8.

Schueler, T. 2009. First Annual Bay-wide Stormwater Performance Scorecard. Chesapeake Stormwater Network, funded by Keith Campbell Foundation.

Schueler, T. 2001. The grass crop in the Chesapeake Bay watershed. Envirocast: Weather and Watershed Newsletter. National Environmental Education and Training Foundation, Washington, DC.

Schueler, T and Holland, H, Eds. 2000. The Peculiarities of Perviousness: Article 129. The Practice of Watershed Protection. Center for Watershed Protection (CWP), Ellicott City, MD.

Swann, C. 1999. A Survey of Resident Nutrient Behavior in the Chesapeake Bay Watershed. Center for Watershed Protection, CR Consortium,Ellicott City, MD.

Theobald, D.M., S.J. Goetz, J.B. Norman, and P. Jantz. 2009. Watersheds at Risk to Increased Impervious Surface Cover in the Conterminous United States. Journal of Hydrologic Engineering: 362-368.

United States Environmental Protection Agency (U.S. EPA). 2010a. Chesapeake Bay Total Maximum Daily Load for Nitrogen, Phosphorus, and Sediment. December 29, 2010.

United States Environmental Protection Agency (U.S. EPA). 2010b. Assessment Total Maximum Daily Load (TMDL) Tracking and Implementation System (ATTAINS) database. http://www.epa.gov/waters/ir/ (retrieved September 27, 2010).

United States Environmental Protection Agency (U.S. EPA). 2010c. Chesapeake Bay Phase 5 Community Watershed Model in Preparation. Chesapeake Bay Program Office.

United States Environmental Protection Agency (U.S. EPA), Office of Inspector General (OIG). 2007. Evaluation Report: Development Growth Outpacing Progress in Watershed Efforts to Restore the Chesapeake Bay. Report No. 2007-P-00031.

United States Geological Survey (USGS). 2010. Complete Listing of NAWQA's Study Units and Summary Reports.

United States Geological Survey (USGS). 2009. Management of Urban Stormwater Runoff in the Chesapeake Bay Watershed. Fact Sheet 2008-3101.

United States Geological Survey (USGS). 2007. Synthesis of U.S. Geological Survey Science for the Chesapeake Bay Ecosystem and Implications for Environmental Management. Circular 1316. S.W. Phillips, editor.

United States Government Accountability Office (U.S. GAO). 2005. Chesapeake Bay Program: Improved Strategies are Needed to Better Assess, Report, and Manage Restoration Progress. Report to Congressional Requesters. GAO-06-96.

United States Government Accountability Office (U.S. GAO). 2008. Chesapeake Bay Program: Recent Actions are Positive Steps Toward More Effectively Guiding the Restoration Effort. Testimony Before the Subcommittee on Water Resources and Environment, Committee on Transportation and Infrastructure, House of Representatives. Statement of Anu K. Mittal, Director: Natural Resources and Environment. GAO-08-1033T.

Zappia, H. 1996. Chlordane, DDT, PCB’s, and other selected organic compounds in asiatic clams and yellow bullhead in the Potomac River Basin, 1992. Geological Survey Water-Resources Investigations Report 96-4210.

Appendix A: Summary of Studies on the Impacts of Urbanization to Aquatic Ecosystems

Urbanization and its associated stormwater runoff can have a wide variety of impacts on aquatic ecosystems. Table 8 (adapted from Beach, 2002) provides an overview of some studies conducted between 1980 and 2000, which suggest that when more than 10% of a watershed is covered in impervious surfaces, aquatic ecosystems become degraded.

Table 8: Impacts of Urbanization on Stream Biotic Indicators (adapted from Beach, 2002)

Biological Parameter	Key Finding	Reference
Fish habitat/channel stability	Channel stability and fish habitat quality declined rapidly after 10% imperviousness	Booth (1991)
Brown trout	Abundance and recruitment of brown trout declines sharply at 10% to 15% imperviousness	Galli (1994)
Aquatic insects	Negative relationship between number of insect species and urbanization in 21 streams	Benke, et al. (1981)
Aquatic insects	Urban streams had sharply lower diversity of aquatic insects when human population density exceeded 4 persons per acre (estimated 15% to 25% impervious cover)	Jones and Clark (1987)
Fish spawning	Resident and anadromous fish eggs and larvae declined sharply in 16 tributary streams greater than 10% imperviousness	Limburg and Schmidt (1990)
Aquatic insects	Insect diversity at 19 stream sites dropped sharply at 8% to 15% imperviousness	Shaver, et al. (1994)
Habitat quality	Strong relationship between insect diversity and habitat quality; majority of 53 urban streams had poor habitat	Shaver, et al. (1994)
Fish	Fish diversity declined sharply with increasing imperviousness, loss in diversity began at 10% to 12%	Schueler and Galli (1992)
Aquatic insects	Insect diversity metrics in 24 subwatersheds shifted from good to poor over 15% imperviousness	Schueler and Galli (1992)
Fish/insects	Fish, insect, and habitat scores were all ranked as poor in 5 subwatersheds that were greater than 30% imperviousness	Black and Veatch (1994)
Aquatic insects/fish	Macroinvertebrate and fish diversity declined rapidly after 10% imperviousness	Klein (1979)

Table 8: Impacts of Urbanization on Stream Biotic Indicators (adapted from Beach, 2002)		
Biological Parameter	**Key Finding**	**Reference**
Fish	Marked shift from less tolerant coho salmon to more tolerant cutthroat trout populations noted at 10% to 15% imperviousness at 9 sites	Luchetti and Fuersteburg (1993)
Aquatic insects	Strong negative relationship between biotic integrity and increasing urban land use/riparian condition at 209 stream sites. Degradation begins at about 10% impervious surface	Steedman (1988)
Aquatic insects	Macroinvertebrate community shifted to chronomid, oligochaetes, and amphipod species tolerant of unstable conditions	Pederson and Perkins (1986)
Salmon	Marked reduction in coho salmon populations noted at 10% to 15% imperviousness at 9 sites	Steward (1983)
Wetland plants and amphibians	Mean annual water fluctuation was inversely correlated to plant and amphibian density in urban wetlands. Sharp declines noted at 10% imperviousness	Taylor (1993)
Aquatic insects	Drop in taxa from 13 to 4 noted in urban streams	Garie and McIntosh (1986)
Aquatic insects/fish	100% of 40 urban sites sampled had fair to very poor index of biotic integrity scores	Yoder (1991)